



R.C.A. INSTITUTES

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Technical Lesson 8

ELECTRICAL CIRCUITS

All substances (according to the electron theory) are electrical in nature. Supported by the electron theory we find that if a pressure or force, electrically called an electromotive force is applied to a copper wire the electrons, which are a part of the copper atoms, will move from one part of the copper to the other. Copper wire is used extensively for radio and electrical purposes in general.

In previous lessons we learned that, years ago, scientists discovered methods to create this electromotive force and when it was applied to a metal it agitated these small electrons at such velocity as to shift or move the electric energy around at a great rate of speed.

Copper ore, which is mined, is sent to a refining plant and the pure copper is extracted from it. This, in turn, can be made into any shape, such as wire, by heating it and sending it through small holes in a steel plate, which is called a die. If the wire is too large it can be sent through a succession of these steel dies each having a smaller opening than the preceding die until the size desired is obtained.

Our study of primary cells taught us that an electromotive force is produced when two elements are placed in an acid solution. When zinc is employed as one of the elements it is attacked by the acid which causes a difference of potential and which, in turn, pushes electrons through the acid solution out of the carbon connection of the cell. The force applied results in an electron movement which we call current.

In Figure 1 and 1A we have a cell capable of developing one volt of electromotive force. If we connect a wire from the positive terminal to the negative terminal of this cell current will flow in the direction of the arrows. Figure 1 represents the picture of the cell while Figure 1A is the electrical symbol or short-hand way of showing the same thing. This is a simple electrical circuit and, around it millions of electrons are in motion.

If you secure a dry cell and connect it up as shown, and then hold the short wire with one hand at any point between X and X1, you will not receive a shock as you might suppose but if you are not careful you may receive a burn such as you would experience by touching a hot iron.

Something is wrong here, can you imagine what it is? Let us disconnect one end of this circuit before it ruins the cell. First, you should know you have caused what is called a SHORT CIRCUIT; if you had several cells connected together the wire might become red hot and even melt.

By referring to the section dealing with resistance and conductance it was found that silver was a very good conductor but its cost is high. Copper is used commercially because of its lower cost and relatively high conductivity. Copper has a high conductivity because its molecular structure is such that the atoms do not have the electrons bound up very tightly. Therefore if an E.M.F. is applied to the copper wire the electrons start off at a terrific rate of speed and they have so many collisions at such a terrific rate of speed in their endeavor to move ahead of the electromotive force or voltage that the entire wire gets hot due to this violent agitation. This causes a short circuit. You either destroy the battery because the zinc will be consumed in a short time or the wire, if small enough, might burn and melt, thus opening the circuit. Short circuits must be prevented.

When you studied the lesson on resistance you found that certain substances would not allow such free movement of electrons; now we are getting to it. We want something that will put a brake on the electrons, preventing them from burning up the very conductor of which they are a part and in which they move.

Resistance then is what we need; something to resist or oppose the movement of electrons and hold them down to a slower pace. Now is the time we are going to put into practice what we learned about electrical units, and our first problem is going to be with the circuit of Figure 1. We found that the wire which made up the external circuit became hot, so we must find a resistance that will check the flow of current.

Let us work out a problem that you can apply in your radio circuits. We will redraw Figure 1 to look like the circuit, Figure 2, and work out the conditions of the problem which is as follows:

With a battery having an E.M.F. of six volts find the resistance necessary to allow one half ampere to flow. From Ohm's Law:

$$R = \frac{E}{I} \text{ substituting } R = \frac{.5)60}{10} \text{ or, } 12 \text{ OHMS}$$

resistance is necessary to pass one half ampere of current in our circuit of Figure 2.

In Figure 3 we have the same type of circuit with different values. Consider the E.M.F. supply in this case to be four volts and we wish to know the resistance necessary to pass ten amperes. From Ohm's Law again

$$R = \frac{E}{I} \text{ and substituting } R = \frac{4}{10} = 0.4 \text{ or a}$$

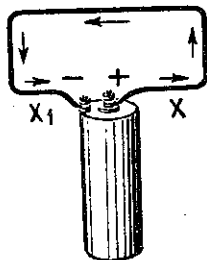


Figure 1

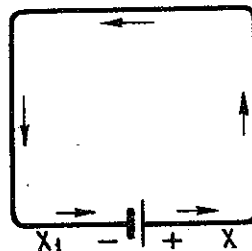


Figure 1A

resistance of four tenths (0.4) of an ohm is required. It is evident that if we know any two factors we can find the third by Ohm's Law in any direct current circuit. If that is so, suppose we consider Figure 4 and prove our statement. $R = .4$ ohms, $I = 10$ amperes and, we will say, the voltage or E.M.F. is unknown. From Ohm's Law $E = I \times R$, therefore $E = 10 \times .4 = 4$

$\frac{4}{10}$, or four volts pressure or E.M.F. necessary to drive ten amperes through the circuit. Now let us refer to the circuit in Figure 5. Here the resistance and the voltage is known, and the current flow, we will say, is unknown, so from Ohm's Law:

$$I = \frac{E}{R}, \text{ substituting } I = \frac{4}{.4} = 10 \text{ amperes,}$$

or ten amperes will flow in the circuit.

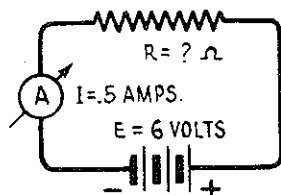


Figure 2

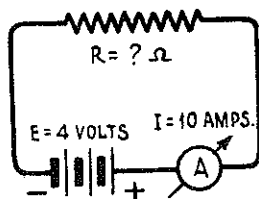


Figure 3

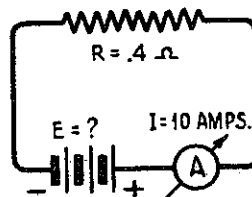


Figure 4

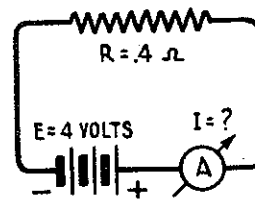


Figure 5

We have now worked out all the three factors, - resistance, voltage and current which are found in all electrical circuits of this kind. It is problems such as these that you encounter in your Radio work so we will now consider an actual circuit.

Our first consideration will be filament circuits applied to radio tubes. The filament circuit is a very important part of the set and one which seems to confuse the average student.

You already know the meaning of voltage, amperage, and ohms but let us repeat them briefly.

Volts (E) = the electromotive force applied.
 Amperes (I) = the current flow in the circuit.
 Ohms (R or Ω) = the opposition or resistance to the current flow.

The voltage will be found to be a very important factor of Ohm's Law for the reason that upon it depends the amount of current flowing through a given resistance. Further, if E.M.F. is held constant and for any reason we change the value of the resistance, the value of current flow will change. Also, if a constant resistance is maintained and the E.M.F. is varied the current will change. Now we can get right down to facts, - things you want to know. Suppose you have a UX-199 tube and wish to know the correct value of the resistance to be used in series with the battery and filament to pass the correct value of current through the tube filament.

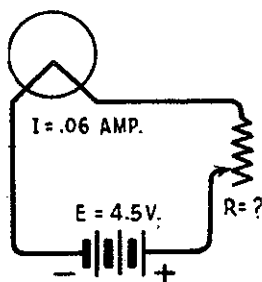


Figure 6A

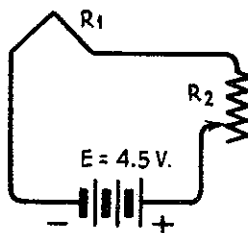


Figure 6B

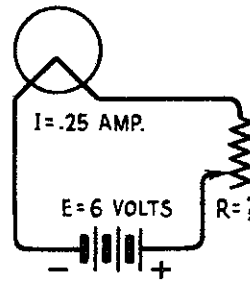


Figure 7A

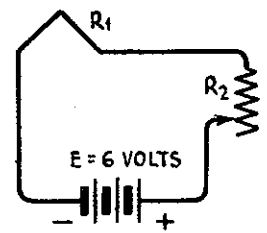


Figure 7B

To begin with the manufacturer tells you on the carton enclosing the tube that the normal current flow in the filament of a UX-199 is .06 amperes and the normal operating voltage is 3 volts.

In practice, however, we must use a source of voltage slightly higher than the rated voltage of the tube to compensate for a voltage drop or loss in the circuit and still have the required 3 volts at the tube terminals. Three dry cells are used each delivering 1.5 volts, connected in series which gives a total voltage of 3 cells times 1.5 volts or 4.5 volts. In Figure 6A we have represented a filament circuit of one UX-199 tube and a rheostat, therefore, from Ohm's Law we can calculate the resistance required to heat the filament by allowing the proper current to flow.

$$R = \frac{E}{I} \text{ substituting } R = \frac{4.5}{.06} = 75 \Omega \text{ Resistance.}$$

But in this circuit as shown in Figure 6B there are two resistances i.e., tube filament resistance and rheostat resistance. We will again resort to Ohm's Law and determine what the resistance of the filament itself is from the figures given by the manufacturers.

$$R = \frac{E}{I} \text{ substituting } R = \frac{3}{.06} = 50 \text{ Ohms.}$$

The next and final step is to subtract the result of our second problem, $50\sim$, (the resistance of filament), from the result of our first problem, or $75\sim$, or $75 - 50 = 25$ ohms. 25 ohms then is the required rheostat resistance to be used in a series circuit using one UX-199 tube.

Figures 7A and 7B show a similar circuit. This time we will use a UX-201A tube. The figures denote the values to be used in solving the problem.

First let us find the resistance of the filament. The manufacturer states that five volts should be applied to the filament and, at that voltage the tube will pass .25 amperes. This is the normal current at which the filament functions best.

$$R = \frac{E}{I} \text{ substituting, } R = 5 \div .25 = 20 \text{ Ohms.}$$

When using a six volt battery then,

$$R = \frac{E}{I} \text{ substituting, } R = 6 \div .25 = 24 \text{ Ohms.}$$

24 ohms minus 20 ohms = 4 ohms. Therefore 4 ohms will be the proper rheostat resistance to use to secure the correct filament current in a UX-201A tube under these conditions. As you may have difficulty in securing a variable 4 ohm rheostat you must take the next larger size made which is 5 ohms. From these few problems and diagrams you will be able to visualize what an electrical circuit is. It is possible to build up an electrical circuit which is really complex, that however is not our intention just yet. We want you to master the simple circuits first and in doing this the more complex circuits to come later will be easy.

TYPES OF ELECTRICAL CIRCUITS

There are three general types of electrical circuits in use. The first is a simple series circuit such as you have just studied, then comes the parallel circuit and following that is the series-parallel circuit.

Don't you think this is interesting? Suppose you want to know what resistance to employ with three UX-201A tubes connected in parallel, and using a 6 volt battery.

Before we work this out let us go over that part of Ohm's Law which refers to parallel circuits and which tells us that if we connect a number of resistances of equal value in parallel, the current flowing through that divided circuit will equally divide through each resistance. For example, in Figure 8 we have an electrical circuit in which we have placed three resistances in parallel to the line, (the line is the connecting leads which carry the current from the batteries to the resistances and from the resistances back to the battery). Now, as the current leaves the battery it flows as indi-

cated by the arrows in Figure 8 through line X until it arrives at point A. At this point it will divide itself and flow through path R1, R2, and R3. If these three paths are equal in the resistance they offer to this current, the current will divide itself equally between the three paths, one third of the total current going through each path. Let us say, for example, the total line current is .75 of an ampere. .25 ampere then will flow through R1, .25 ampere through R2 and .25 ampere through R3. As soon as it passes through this divided circuit arriving at point B the total current returns to the battery through line X1 as .75 amperes. Since we have combined three resistances in parallel this combined resistance will be less than either resistance taken separately. For example, if R1 equals R2, and R2 equals R3 then the three together in parallel will offer less resistance to the current than either R1, R2, or R3 taken separately. Now suppose R1, R2 or R3 taken separately are 20 ohms each. When connected in parallel the resistance of the three together equals 6.66 ohms, or the total resistance. Now we can continue with our three tube radio circuit which we show in Figure 9. By studying Figure 9A you can see it is the same, and if you further notice the dotted lines of Figure 8 you will see the same circuit drawn differently.

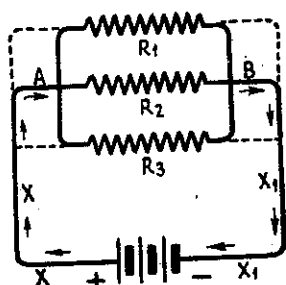


Figure 8

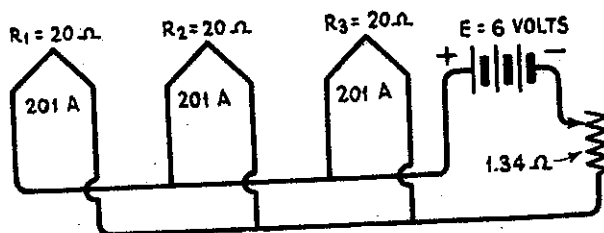


Figure 9

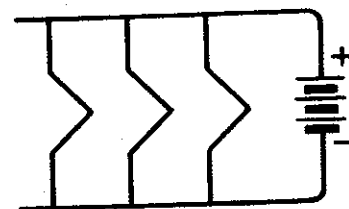


Figure 9A

With that settled we can get at our problem.

1st step. The manufacturer states the tube will function at its best when exactly 5 volts is applied and .25 amperes flows through the filament. The resistance of the filament of one tube then is found by Ohm's Law.

$$R = \frac{E}{I} \text{ substituting, } R = \frac{5 \text{ volts}}{.25 \text{ amperes}} \text{ or } .25)5.0(20 \Omega$$

or $R = 20 \text{ ohms}$ for one filament when 5 volts is applied causing a current of .25 amperes to flow.

2nd step. The resistance of one filament is 20 ohms. Now the law of resistance in parallel tells us that if we connect three equal resistances in parallel the combined resistance of the three will be less than any one taken alone and as R1, R2 and R3 are equal (20 ohms each), then their total resistance in parallel will equal the resistance of them divided by the number of resistances in parallel, i.e., 20 ohms divided by 3 or

$$3)20.00(6.66 \Omega \text{ for the total three parallel filaments.}$$

$$\begin{array}{r} 18 \\ \underline{20} \\ 20 \\ \underline{20} \\ 20 \end{array}$$

3rd Step. The applied E.M.F. of 5 volts must be constant in order that the current will be constant. Therefore we use an E.M.F. supply slightly higher than 5 volts, generally a 6 volt storage battery. This assures us of 5 volts constantly for quite long periods before the battery requires charging. The current through each filament is .25 amperes and we have three filaments, therefore 3 filaments times .25 amperes equals .75 amperes, the total current required.

4th step. With that known our job now is to find out what resistance will pass .75 amperes at 6 volts potential, and as

$$R = \frac{E}{I} \text{ and substituting, } R = \frac{6 \text{ volts}}{.75 \text{ amperes}} \text{ and worked out } \frac{.75)6.00}{6.00}$$

or 8 ohms, the value of resistance required.

5th step. But from step 2 it was found we already have a resistance in the circuit represented by the filaments themselves amounting to 6.66 ohms.

6th step. Therefore we subtract that from the result found in step 4, or 8.00 ohms - 6.66 ohms and worked

$$\begin{array}{r} 8.00 \\ -6.66 \\ \hline 1.34 \text{ ohms} \end{array}$$

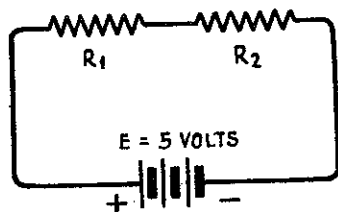


Figure 10

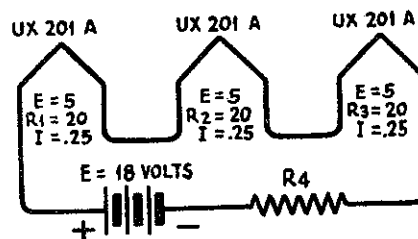


Figure 11

or approximately 1.34 ohms of rheostat resistance required to control the filaments of three UX-201A tubes.

7th step. This method gives the exact amount of resistance necessary to control the required current for three UX-201A tubes. In this case you need a two ohm variable rheostat and, if the store does not carry this size, you will probably have to buy the next larger size or 6 ohms.

Now we will consider the series circuit as shown in Figure 10. The current flowing throughout this circuit will be the same as that through every resistance regardless of their value. Suppose the resistance of R1 is 20 ohms and that of R2 is 20 ohms; to find the total resistance simple add, thus $20 + 20 = 40$ ohms. The current at a potential of 5 volts as found by Ohm's Law will be

$$I = \frac{E}{R} \text{ substituting the above values we have } I = \frac{5 \text{ volts}}{40 \text{ ohms}}$$

and worked out, $I = 40)5.000(.125$ or .125 amperes, the same current flowing through R1 and R2.

$$\begin{array}{r} 4.0 \\ 1 \overline{)00} \\ 80 \\ \underline{200} \\ 200 \end{array}$$

When filaments are connected in parallel the voltage across each tube is the same, but when connected in series the voltage supply must equal the voltage required by one tube times the number of tubes. In Figure 11 we have represented the filaments of three UX-201A tubes. Each tube is designed to operate at an E.M.F. of 5 volts. There are three in series, however, and 3 tubes x 5 volts equals 15 volts. While it only required 5 volts to operate 3 tubes connected in parallel it requires 3 times the voltage, namely 15 volts, to do the same thing when you connect the filaments in a series arrangement. In all cases of series arrangements it is best to have a battery supply slightly over the required voltage necessary, so in Figure 11 we have indicated that voltage as 18 volts. Three six volt storage batteries are easy to obtain and the three in series give us a margin of 3 volts to spare over the required voltage.

The current throughout the line will be the same as required by one tube. (Remember in parallel circuits the current flowing was the sum of all the tubes.)

With these facts in mind find the resistance, R4, necessary to control the voltage. Proceeding with Ohm's Law

$$R = \frac{E}{I} \text{ substituting, } R = \frac{15 \text{ volts}}{.25 \text{ amperes}} = \frac{.25)15.00(60 \text{ ohms}}{15 \ 0}$$

or 60 ohms, the resistance of the tubes at 15 volts and .25 amperes flowing. But we are going to use 18 volts to allow for a drop of voltage

$$\text{in the line therefore } R = \frac{E}{I} = \frac{.25)18.00(72 \text{ ohms total resistance.}}{17 \ 5} \\ \underline{50} \\ 50$$

$72 - 60 = 12$ ohms required for the rheostat, R4, to control the three UX-201A tubes in series.

Now if we know the amount of the current flow and total resistance in the circuit given we could compute the voltage required by proceeding as follows; where the total resistance is 72 ohms and the total current flow is .25 then $E = I \times R$, or

$$\begin{array}{r} 72 \\ .25 \\ \hline 360 \\ 144 \\ \hline 18.00 \end{array} \text{ volts.}$$

In this work we have neglected all resistance of other parts of the circuit. However, if a very close measurement were to be made, every single part of the circuit resistance would have to be known; each length of wire, every switch, in fact all parts of any electrical circuit has some resistance, but for the general results this factor is so small it is not considered.

We can review the three general circuits with which you will come in contact and we will give you a formula for each one, then when you have a problem you can easily work it out. This may apply to the student who wishes to go into Ohm's Law more thoroughly. We will take a series circuit first, as shown in Figure 12. The total resistance, R , equals $R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7 + R_8$.

$R_4, 5, 6, 7$, is the internal resistance of the battery, while R_8 equals the resistance of the connecting wires. In our calculations

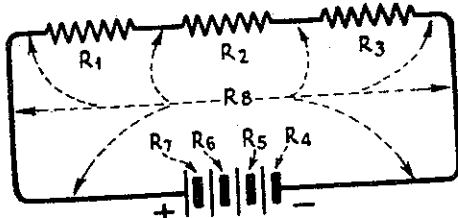


Figure 12

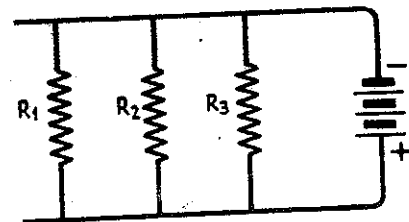


Figure 13

which do not have to be very close $R_4, 5, 6, 7, 8$ can be omitted, and then the formula becomes: $R = R_1 + R_2 + R_3$.

Figure 13 illustrates a parallel circuit wherein we have three parallel resistances. If the resistances R_1, R_2 and R_3 are equal then the current divides equally between them.

If the resistances are not equal the current dividing between them is in inverse proportion to the individual resistances. That is to say, the lowest resistance will carry the most current. Furthermore, the total resistance offered to the flow of current by such a parallel connection is always less than the smallest resistance in such a circuit. In other words, as more resistances are connected in parallel in a circuit, it's total resistance is decreased.

In Figure 13 $R_1 = 30$ ohms, $R_2 = 20$ ohms, $R_3 = 10$ ohms. What is the total resistance of the three, disregarding the resistance of the connecting leads? The formula for this will be:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

and substituting our values we have

$$R_T = \frac{1}{\frac{1}{30} + \frac{1}{20} + \frac{1}{10}}$$

obtain a common denominator of 60,

$$\text{then } R = \frac{2}{60} + \frac{3}{60} + \frac{6}{60} = \frac{11}{60} = 1 \times \frac{60}{11} = \frac{60}{11} =$$

11) 60.00 (5.45

$$\begin{array}{r} 55 \\ 50 \\ 44 \\ 60 \\ 55 \end{array}$$

ohms, the answer, and the total resistance of 30, 20 and 10 ohms connected in parallel. This value, you will note, is less than that of the smallest resistance of 10 ohms.

We will consider a problem now with resistance both in series and parallel, making a series-parallel circuit as shown in Figure 14. In this problem we are considering the entire circuit. In any electrical circuit every piece of wire, every piece of apparatus, no matter how small, has resistance and to know accurately the resistance in any given circuit we must know it all, therefore, in the problem shown in Figure 14 we are considering the internal resistance of the battery as one ohm. (Note: A dry cell is less than 0.1 ohm. Shelf life and use however, increase this and the resistance may, within a year, increase to 0.5 ohm.) The wire used to connect up the resistances we

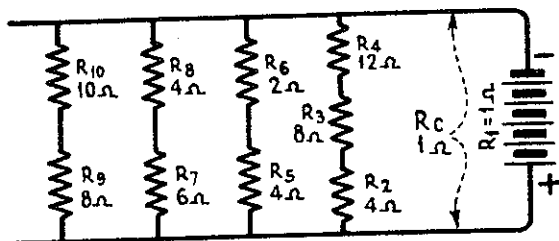


Figure 14

will assume is one ohm. This resistance is in series with the line while in other parts resistances are connected first in series, and in series arrangements, then connected in parallel with the source of electromotive force.

We will work the problem out step by step in order that you will be able to follow it easily. Taking our values from Figure 14 our formula will be:

$$R = 1 + 1 + \frac{1}{\frac{1}{R_2 + R_3 + R_4} + \frac{1}{R_5 + R_6} + \frac{1}{R_7 + R_8} + \frac{1}{R_9 + R_{10}}}$$

$$\text{Substituting, } R = 1 + 1 + \frac{1}{\frac{1}{12 + 8 + 4} + \frac{1}{4 + 2} + \frac{1}{6 + 4} + \frac{1}{10 + 8}}$$

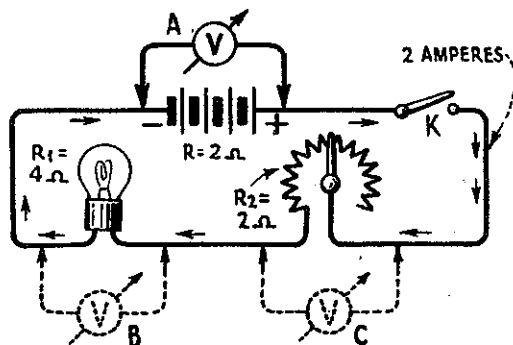
$$R = 1 + 1 + \frac{1}{\frac{1}{24} + \frac{1}{6} + \frac{1}{10} + \frac{1}{18}}$$

$$R = 1 + 1 + \frac{1}{\frac{131}{360}} \quad \text{clearing denominator} \quad \begin{array}{r} 0.3638+ \\ \hline 131.0000 \\ 1080 \\ \hline 2300 \\ 2160 \\ \hline 1400 \\ 1080 \\ \hline 3200 \\ 2880 \end{array}$$

In electrical parlance voltage drop is often referred to as the "IR drop". To explain the above expression we will use Figure 15. Here we have a circuit consisting of a battery, a lamp and a rheostat with the necessary connecting wires, and a key "K". The lamp represents a resistance of four ohms, while the rheostat represents a resistance of 2 ohms. Now close switch "K" and place the terminals of a voltmeter across the battery as at position A. The voltmeter reads 12 volts. We can apply Ohm's Law to find the current flowing and, as the resistances are in series, the current will be the same in all parts of the circuit. Therefore the total external resistance is equal to $R_1 + R_2$, and substituting the known values of the resistances: $R_1 = 4\text{ }\Omega$; then R equals $4 + 2 = 6\text{ }\Omega$. Figuring the current flow.

$$I = \frac{E}{R} \text{ or } I = \frac{12}{6} = 2 \text{ amperes.}$$

Remove the voltmeter from position "A" and, connecting it at point "B" across the filament terminals of the lamp, you will notice that it reads 8 volts, indicating there is an 8 volt drop of potential across this filament resistance. Now place it as shown at point "C" and again take a reading: This time it will read 4 volts, indicating a drop of four volts across this resistance.



8 volts then is the proportion of the total of 12 volts required to force 2 amperes through the lamp resistance of 4 ohms, while 4 volts is that proportion of 12 volts required to force a current of 2 amperes through the rheostat resistance.

MEASURING UNKNOWN RESISTANCE

In your radio work it may be necessary at times for you to know the value in ohms of a certain resistance. You may find this unknown resistance by one of two methods which will be described. The first is with an ammeter and voltmeter and the second is by the use of the Wheatstone Bridge. In the voltmeter-ammeter method both meters should be first class instruments, the voltmeter especially should be of the high resistance type in order to obtain good results. This method will give results close enough for practical purposes and can be used without going to much expense. The Wheatstone Bridge method requires rather expensive apparatus for this purpose and generally is employed only where very accurate results are necessary. First let us refer to Figure 16 and see of what the circuit is composed. "V" is a voltmeter of high resistance, thus passing very little current. An ammeter "A", a key "K", a battery, and a rheostat "R" of unknown resistance are included in the circuit. Our purpose is to find the

value of the rheostat resistance. This we can do by the voltmeter-ammeter method.

Note the arrangement of the circuit. First place the two meters in some position convenient to you when doing the work. Connecting up the circuit;- from the positive side of the battery run a lead to one side of the rheostat, then secure another piece of wire to the opposite side of the rheostat and connect that to one side of the ammeter; from the other side of the ammeter run another lead to the key and then another wire back to the negative side of the battery. Now connect the voltmeter across the rheostat as shown and close the key. The circuit is closed and current flows through the line. Now take a reading of the voltmeter and also the ammeter. With these readings substituted in the following formula:

$$R = \frac{E}{I}, \text{ find out the resistance of the rheostat.}$$

For example, when we close the key suppose the voltmeter reads 5 volts and the ammeter reads .25 amperes. Substituting these values in the

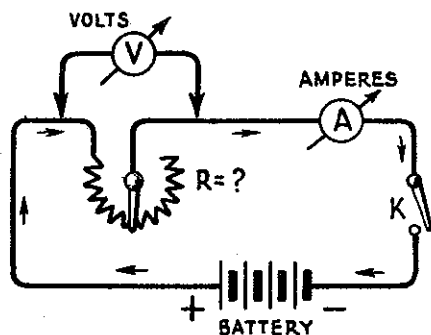


Figure 16

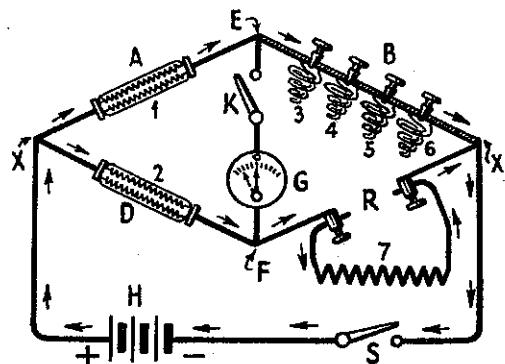


Figure 17

above formula we have

$$R = \frac{E}{I} \text{ or } R = \frac{5 \text{ volts}}{.25 \text{ amperes}} = \frac{5.0}{.25} = 20 \text{ ohms}$$

answer. Twenty ohms then is the value of the rheostat.

The Wheatstone Bridge method of measuring resistances is a very accurate method and is used in laboratories where the resistance of certain lengths of wire and other electrical apparatus must be definitely known. There are bridges of various types and capacities on the market, that is, the physical appearances of some are different than others and some are designed to measure small resistances while others are used for measuring very large resistance values. Some will measure any unknown resistance from a value of less than one ohm to thousands of ohms. The principle however, is the same and, knowing the principle of one, you can easily

apply it to another design. The general lay out of the Wheatstone Bridge is shown in Figure 17 and consists of a circuit in which known resistance is connected and connections provided for the resistance to be measured. Beginning with a battery "H", a wire is run from the positive side to point "X". At this point the circuit is so arranged that it divides as shown at "X". At "X" an arm is run to point "E"; this is called an arm of the bridge and is designated in the drawing as arm "A". In this arm a connection is made for plugging in resistance units of known value shown as 1. From "X" to "F" arm "D" is run with the same provisions for plugging in or out resistance units. Arm "A" and "D" have a resistance of 2 each. From "E" to "X1" and from "F" to "X1" arms "B" and "R" are respectively connected. Arm "B" is provided with brass plugs which tightly fit into a brass strip so that the non-inductive resistance coils 3, 4, 5, 6, may be shorted or cut out of the circuit at the will of the operator. The resistances of these coils are also accurately known and indicated.

Arm "R" is the arm or branch of the bridge circuit in which the unknown resistance to be measured is connected, binding posts being provided to connect the ends of the unknown resistance in the bridge circuit as indicated.

When the switch "S" is closed, current flows from the battery "H" to point "X" where it divides, part flowing through arms "A" and "B" to point X1 and part through arms "D" and "R" to point X1, - here it returns to the battery.

With current flowing as indicated we are ready to work on the unknown resistance "7" in arm "R"; that is, we are to find out what the value of that resistance is. The principle on which the bridge circuit works is that the current flowing from the battery "H" must, when it reaches point X, divide itself equally, provided the resistances of the four arms of the bridge are balanced. Then the current flowing from the battery "H" through points X, A, E, B, to X1 will be the same as that which flows through points X, D, F, R, to X1. For example, if the total current through the circuit is 4 amperes, then 2 amperes must flow through the arms "A" and "B" and 2 amperes through arms "D" and "R". Now supposing this is the case, if we close the switch "K", the galvanometer will not be deflected, in other words, it will remain on zero as shown, indicating that there is no difference of potential between points "E" and "F" of the divided circuit. As a general rule, however, when a bridge is used and all necessary connections made, on closing key "K" the galvanometer needle is deflected as shown by the dotted arrow. This denotes a difference of potential across points "E" and "F", thus indicating that more current flows in arms "A" and "B" than through arms "D" and "R" or vice versa. Our object now is to vary the resistance in arm "B" to the extent that no difference of potential exists between points "E" and "F", as determined when no deflection of the galvanometer needle is obtained or in other words, exactly the same current will then flow through points X, A, E, B, X1, as through points X, D, F, R, X1. When that condition exists we can find the

unknown resistance "R" by the following formula: Unknown resistance "R" equals the resistance of the arm "B" times the resistance of arm "D" divided by the resistance of the arm "A".

$$R = \frac{B \times D}{A}.$$

The entire procedure can be summed up as follows;- by the use of a known variable resistance (B) we can establish a condition of electrical balance between points E and F (as denoted by no deflection of the galvanometer needle). There are then in the circuit three known and one unknown resistances. When such a balance is obtained (by adjusting B) we can apply these three known values to the equation to give the fourth, or unknown value. This method of determining the values of unknown resistances is very accurate when carried out with precision instruments.

EXAMINATION - LESSON 8

1. What is an electrical circuit?
2. What is a short circuit?
3. What value of resistance will pass one ampere under a pressure of 6 volts?
4. To what extent will three parallel resistances of equal value increase the total number of amperes in a circuit over that when only one is used?
5. What is meant by the term "voltage drop"?
6. What is a Wheatstone Bridge used for?
7. If the tubes in a radio receiver require 5 volts would you use a 5 volt source of supply?
8. Draw a diagram of an electrical circuit in which five resistances are connected in series.
9. Draw a diagram of an electrical circuit with four resistances in parallel, and two in series with the line.
10. How would you determine the value of an unknown resistance by the ammeter-voltmeter method?